Fishery Data Series No. 14-42

Estimates of Total Annual Return of Coho Salmon to the Kuskokwim River, 2001–2005, 2008 and 2009

Final Report for Project 801 and 45716
Arctic-Yukon-Kuskokwim Sustainable Salmon Initiative

by

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October 2014

Alaska Department of Fish and Game — Divisions of Sport Fish and Commercial Fisheries

Symbols and Abbreviations

The following symbols and abbreviations, and others approved for the Système International d'Unités (SI), are used without definition in the following reports by the Divisions of Sport Fish and of Commercial Fisheries: Fishery Manuscripts, Fishery Data Series Reports, Fishery Management Reports, and Special Publications. All others, including deviations from definitions listed below, are noted in the text at first mention, as well as in the titles or footnotes of tables, and in figure or figure captions.

Weights and measures (metric)

centimeter	cm
deciliter	dL
gram	g
hectare	ha
kilogram	kg
kilometer	km
liter	L
meter	m
milliliter	mL
millimeter	mm

Weights and measures (English)

cubic feet per second	ft^3/s
foot	ft
gallon	gal
inch	in
mile	mi
nautical mile	nmi
ounce	oz
pound	lb
quart	qt
yard	yd

Time and temperature

day	d
degrees Celsius	°C
degrees Fahrenheit	°F
degrees kelvin	K
hour	h
minute	min
second	s

Physics and chemistry

all atomic symbols	
alternating current	AC
ampere	A
calorie	cal
direct current	DC
hertz	Hz
horsepower	hp
hydrogen ion activity (negative log of)	pH
parts per million	ppm
parts per thousand	ppt, ‰
volts	V
watts	W

General

Alaska Administrative Code	AAC
all commonly accepted abbreviations	e.g., Mr., Mrs., AM, PM, etc.
all commonly accepted professional titles	e.g., Dr., Ph.D., R.N., etc.
at	@
compass directions:	
east	E
north	N
south	S
west	W
copyright	©
corporate suffixes:	
Company	Co.
Corporation	Corp.
Incorporated	Inc.
Limited	Ltd.
District of Columbia	D.C.
et alii (and others)	et al.
et cetera (and so forth)	etc.
exempli gratia (for example)	e.g.
Federal Information Code	FIC
id est (that is)	i.e.
latitude or longitude	lat or long
monetary symbols (U.S.)	$, ¢
months (tables and figures): first three letters	Jan,...,Dec
registered trademark	®
trademark	™
United States (adjective)	U.S.
United States of America (noun)	USA
U.S.C.	United States Code
U.S. state	use two-letter abbreviations (e.g., AK, WA)

Mathematics, statistics

all standard mathematical signs, symbols and abbreviations	
alternate hypothesis	H_A
base of natural logarithm	*e*
catch per unit effort	CPUE
coefficient of variation	CV
common test statistics	(F, t, χ^2, etc.)
confidence interval	CI
correlation coefficient (multiple)	R
correlation coefficient (simple)	r
covariance	cov
degree (angular)	°
degrees of freedom	df
expected value	*E*
greater than	>
greater than or equal to	≥
harvest per unit effort	HPUE
less than	<
less than or equal to	≤
logarithm (natural)	ln
logarithm (base 10)	log
logarithm (specify base)	log_2, etc.
minute (angular)	'
not significant	NS
null hypothesis	H_O
percent	%
probability	P
probability of a type I error (rejection of the null hypothesis when true)	α
probability of a type II error (acceptance of the null hypothesis when false)	β
second (angular)	"
standard deviation	SD
standard error	SE
variance	
population	Var
sample	var

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October 2014

This investigation was funded by Arctic-Yukon-Kuskokwim Sustainable Salmon Initiative (Projects 45349, 45565, and 45716) with matching funds from Coastal Villages Region Fund and the State of Alaska.

ADF&G Fishery Data Series was established in 1987 for the publication of Division of Sport Fish technically oriented results for a single project or group of closely related projects, and in 2004 became a joint divisional series with the Division of Commercial Fisheries. Fishery Data Series reports are intended for fishery and other technical professionals and are available through the Alaska State Library and on the Internet: http://www.adfg.alaska.gov/sf/publications/ This publication has undergone editorial and peer review.

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This document should be cited as:
Liller, Z. W., T. Hamazaki, K. L. Schaberg, and B. G. Bue. 2014. Estimates of total annual return of coho salmon to the Kuskokwim River, 2001-2005, 2008 and 2009. Alaska Department of Fish and Game, Fishery Data Series No. 14-42, Anchorage.

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ABSTRACT

Estimates of total annual return of coho salmon *Oncorhynchus kisutch* to the Kuskokwim River drainage were attempted for years 2001–2005, 2008, and 2009 by adding mark–recapture abundance estimates upriver of Kalskag (Birch Tree Crossing) to estimates of escapement and harvest below Kalskag. The Division of Commercial Fisheries conducted mark–recapture studies in 2001–2005, and estimated the annual abundance of coho salmon upstream of Kalskag. Those estimates were based on external tags, and assumptions of population closure and tag loss were not rigorously tested. Additional mark–recapture studies were conducted in 2008 and 2009 using radiotelemetry techniques, and data were used to test assumptions of population closure and tag loss. This new information was used to revise the existing 2001–2005 mark–recapture estimates. For each year, total escapement below Kalskag was estimated by expanding escapements recorded at Tuluksak and Kwethluk River weirs to account for unmonitored tributaries, using a relationship between stream length and escapement. Annual harvest data from the lower river commercial, subsistence, sport, and test fish fisheries were added to upriver mark–recapture abundance estimates and lower river escapement to reconstruct total annual run size. Total run size was estimated for all years except 2005. Annual run size ranged from 603,414 to 2,024,571 fish.

Key words: coho salmon, *Oncorhynchus kisutch*, Kuskokwim River, total abundance, total escapement, radiotelemetry, mark–recapture, run reconstruction.

INTRODUCTION

Management of Kuskokwim River coho salmon (*Oncorhynchus kisutch*) fisheries is challenging due to the large size of the drainage and a lack of information for estimating total annual abundance. The Kuskokwim River is the second largest river in Alaska, and drains an area of approximately 130,000 km^2. Our current understanding of Kuskokwim River coho salmon run dynamics comes from a discontinuous time series of inriver commercial catch and effort data, subsistence harvest estimates, test fishery catch rates, tributary weir counts, and mark–recapture estimates of abundance. Although a substantial amount of data is available, interpretation of that data for sustainable fisheries management is limited because relationships between existing indices of abundance and total abundance are not known. This critical knowledge gap affects fisheries managers' ability to determine biologically appropriate escapement and sustainable harvest levels at the drainagewide scale. The purpose of this study is to develop estimates of coho salmon total abundance.

The need for reliable estimates of total abundance is highlighted by the importance of the Kuskokwim River coho salmon fishery to the local economy and culture and the requirement to manage for sustained yields. The Kuskokwim River supports the largest commercial fishery for coho salmon in western Alaska, with a peak harvest of 937,299 fish in 1996 (Brazil et al. 2013). Coho salmon account for 79% (2001–2010) of the total exvessel value of salmon harvested commercially in the Kuskokwim River (Brazil et al. 2013). Subsistence fishermen annually harvest an average of 37,410 (2001–2010) coho salmon, representing 16% of the total Kuskokwim River subsistence salmon harvest (Hamazaki 2011; Brazil et al. 2013). Annual subsistence harvests have been relatively consistent over time, and typically within the amounts of fish reasonably necessary for subsistence uses (27,400–57,600 coho salmon), established by the Alaska Board of Fisheries. On the contrary, commercial harvests of coho salmon have decreased abruptly since the late 1990s despite continued commercial interest. During the 10 years prior to 1996, average commercial harvest was 544,793 fish, and during the following 10 years harvest averaged only 195,011 fish – a 64% reduction (Brazil et al. 2013). Exploitation rates during both periods are not known, however, the combination of total harvest and indices of escapement suggests that the reduction in harvest was due to an overall reduction in run size rather than a simple reduction in harvest effort.

Coho salmon escapements are monitored at select spawning tributaries intended to index broader geographic areas relevant for management. Kuskokwim River fisheries managers attempt to provide for escapements within a range that will produce sustained yields; however, interpretation of available escapement data from individual weirs is difficult because the proportion of total escapement that the weir counts represent is unknown. Efforts to monitor salmon escapement within the Kuskokwim River began in 1969 on the Kogrukluk River, a headwater tributary of the Holitna River (Hansen and Blain 2013). Beginning in the late 1990s, the Kuskokwim River salmon monitoring program was expanded considerably. By 2008 and 2009, 7 weirs were operated to index escapements to the lower, middle, and upper portions of the drainage (Elison et al. 2009a and 2009b; Stewart et al. 2009; Clark et al. 2010; Miller and Harper 2010a and 2010b; Smith and Shelden 2010; Stewart et al. 2010; Williams and Shelden 2010a and 2010b). For each monitoring location, annual escapements are compared to the range of historical escapements or a formal escapement goal, to index the adequacy of escapement for each salmon species. For coho salmon, escapement goals have been established for the Kogrukluk River in 2005 and for the Kwethluk River in 2010 (Conitz et al. 2012; Munro and Volk 2013). More research is needed to determine how well the weir counts index escapement over broader geographic areas. The only previous study of this kind used mark–recapture methods to determine if the escapement at the Kogrukluk River weir was an adequate index of the Holitna River drainage (Stroka and Brase 2004). Results were inconclusive, but indicated that the weir was likely a reasonable index of Holitna River coho salmon abundance and age, and sex, length composition. However, the percentage of total Kuskokwim River coho salmon run returning to the Holitna River is unknown.

Estimating drainagewide salmon abundance is challenging due to the large size and remoteness of the Kuskokwim River, coupled with the fact that a direct count of all fish returning to the drainage has not been possible. Rather an approach that combines direct and indirect methods to estimate fish abundance is required. Total run size for Chinook salmon (*O. tshawytscha*) returning to the Kuskokwim River was estimated by combining estimates of harvest abundance from large scale mark–recapture experiments, and observed escapements from weirs, and expanding weir counts to unmonitored systems based on available habitat (Schaberg et al. 2012). Similar methods were used in this study to estimate total abundance of Kuskokwim River coho salmon.

Mark–recapture estimates are available for years 2001–2005; however, there are potential sources of bias associated with these estimates that could not be evaluated (Kerkvliet and Hamazaki 2002; Kerkvliet et al. 2003; Kerkvliet et al. 2004; Pawluk et al. 2006a; Pawluk et al. 2006b; Schaberg et al. 2010). Each year bank-mounted fish wheels and drift gillnets were operated in the mainstem Kuskokwim River to capture coho salmon migrating past the community of Kalskag near river kilometer (rkm) 270. Captured fish were tagged with 1 external spaghetti or t-bar anchor tag and the adipose fin was removed as a secondary mark. Recapture sampling occurred at weirs located on the George, Tatlawiksuk, Kogrukluk, and Takotna rivers. Abundance upriver from Kalskag was estimated using a 2-sample model, which assumes, among other things, that the population was closed and that tags do not fall off between the marking and recapture sample events. In all years, tagged fish were documented migrating downriver out of the study area, but the extent of this problem is not known. Assessment of tag loss relied on sampling a relatively small proportion of fish passing each recapture site and examining non-tagged fish for presence of a secondary adipose mark. That approach did not have the necessary power to detect tag loss if it occurred. These issues were identified but, due to study design limitations, they were either ignored or only minor corrections were made. We repeated the 2001–2005 mark recapture studies and incorporated radiotelemetry techniques to investigate the extent of these potential biases. If a substantial bias was detected, the prior year estimates were revised to incorporate new information.

The portion of the Kuskokwim River downriver from where the 2001–2005 mark–recapture studies occurred represents approximately 30% of the total drainage area. Salmon escapement is monitored annually on 2 lower river tributaries: Kwethluk and Tuluksak rivers. However, numerous unmonitored tributaries support coho salmon (Johnson and Daigneault 2008). We decided to estimate potential escapement in unmonitored tributaries by expanding estimates from monitored tributaries based on relative habitat available for smolt production. Our approach was similar to methods used to estimate Kuskokwim River Chinook salmon in data limited situations. Relative productivity among tributaries supporting Chinook salmon was estimated using a habitat-based model (Schaberg et al. 2012) to estimate the number of spawning adults at maximum sustained yield (S_{msy}) based on watershed area (Parken et al. 2006). Ratios of S_{msy} were generated for pairs of monitored and unmonitored tributaries, and annual escapement to each unmonitored tributary was estimated by multiplying the ratio of S_{msy} by the escapement to the monitored tributary (Schaberg et al. 2012). Although this method is unconventional and has high uncertainty, it did provide an objective estimate of escapement to the lower Kuskokwim River. A similar habitat-based model exists for coho salmon. The model estimates mean coho salmon smolt abundance based on stream length (Bradford et al. 1997). The model was developed using data from 83 streams along the west coast of the United States, Canada, and Alaska. Estimates of smolt abundance were used as an index of coho salmon productivity. Annual escapement to unmonitored tributaries was estimated by scaling escapement to nearby monitored tributaries to account for expected differences in production.

This report details the efforts to reconstruct total coho salmon abundance to the Kuskokwim River for the years 2001–2005, 2008, and 2009. Reconstructed estimates are based on all available abundance data, including harvest, escapement, and inriver abundance estimates.

OBJECTIVES

1. Estimate total abundance of Kuskokwim River coho salmon upriver of rkm 294 in 2008 and 2009.
2. Recalculate the estimates of Kuskokwim River coho salmon produced by the Division of Commercial Fisheries in 2001–2005 to account for expected bias due to violations of population closure and tag loss.
3. Estimate the escapement of coho salmon in the lower Kuskokwim River downriver of rkm 294 in 2001–2005, 2008, and 2009.
4. Reconstruct total annual return of Kuskokwim River coho salmon from 2001 to 2005, 2008, and 2009.

METHODS

OVERVIEW

Total annual coho salmon return to the Kuskokwim River was reconstructed by adding the following components: 1) mark–recapture estimates of total coho salmon abundance upriver of kilometer 294; 2) coho salmon escapement estimates based on available habitat downriver of kilometer 294; and 3) total harvest of coho salmon downriver of kilometer 294. The following paragraphs provide an overview of how each of the 3 components was estimated.

The Kuskokwim River is over 1,500 km long and drains an area approximately 130,000 km^2 from its headwaters to the southern tip of Eek Island where it flows into Kuskokwim Bay (Figure 1). For abundance estimation purposes, the watershed was divided into 2 sections and different methods were used for each. River kilometer 294, locally referred to as Birch Tree Crossing, demarked the separation between the lower and upper sections.

Mark–recapture methods were used to estimate abundance of coho salmon in the upper section. The tagging site was located at rkm 270. Weirs located on 5 upriver spawning tributaries were used as recapture sites for tagged fish: Salmon (rkm 404; data on file with the Kuskokwim Research Group, contact Kevin Schaberg, ADF&G Division of Commercial Fisheries; Anchorage), George (rkm 453; Stewart et al. 2009; Clark et al. 2010), Tatlawiksuk (rkm 568; Elison et al. 2009a; Smith and Shelden 2010), Kogrukluk (rkm 710; Williams and Shelden 2010a, 2010b), and Takotna (rkm 835; Elison et al. 2009b; Stewart et al. 2010) rivers (Figure 2).

Ground-based and aerial telemetry tracking methods were used in 2008 and 2009 to monitor movement and determine the final fate of radiotagged coho salmon (Figure 2). One ground-based telemetry station was located at Birch Tree Crossing (rkm 294), representing the downriver boundary of the mark–recapture study area. A distance of rkm 24 separated the tag site and the downriver boundary of the study area to allow tagged fish adequate time to recover from capture and tag stress. One telemetry station was located at rkm 233 and was used to detect fish that swam downriver after tagging. An additional 5 stations were located along the mainstem Kuskokwim River from Aniak (rkm 310) to rkm 863. Six stations were located within major salmon spawning tributaries: 1 in the Aniak River, 3 in the Holitna River, and 1 each in the Stony and Swift rivers. One station was located at each of the 5 weir recovery sites. Multiple aerial survey tracking flights were flown along the mainstem and within each tributary upriver of rkm 233.

Weirs located on the Kwethluk (rkm 216; Miller and Harper 2010a) and Tuluksak rivers (rkm 248; Miller and Harper 2010b) were used from 2001 to 2009 to estimate escapement of coho salmon into those systems. Escapement estimates were not expanded for unmonitored reaches downriver of each weir (Figure 3) because local knowledge suggests that coho spawning activity in those areas is negligible (Dan Gillikin, Fisheries Biologist, USFWS/Bethel; personal communication).

Additional tributaries downriver from Birch Tree Crossing that support coho salmon spawning were identified from the ADF&G Anadromous Waters Catalogue (AWC; Johnson and Daigneault 2008). Annual coho salmon escapement into these systems was estimated with the aid of a habitat production model (Figure 3). The Johnson River is a relatively large tundra tributary that was not identified in the AWC as a significant coho salmon spawning area and was therefore not included.

Commercial harvest was from District W-1, defined as the mainstem Kuskokwim River from the southern tip of Eek Island to Bogus Creek, located just upstream of the Tuluksak River. Subsistence harvests were from 18 communities ranging from Tuntutuliak (rkm 45) to Upper Kalskag (rkm 263) including 3 North Kuskokwim Bay communities that typically fish at the mouth of the Kuskokwim River. Test fish harvest was from a test fishery located near Bethel.

Sport harvest was from the entire Kuskokwim River, inclusive of areas upriver from Birch Tree Crossing.

Abundance Upstream of Birch Tree Crossing, 2008 and 2009

In 2008 and 2009, a closed population 2-sample mark–recapture study design (Chapman 1951; Seber 1982) was used to estimate population abundance (i.e., total escapement and harvested fish) of coho salmon upstream from Birch Tree Crossing.

Marking and Tracking

Coho salmon were captured from the mainstem Kuskokwim River using 2 bank mounted fish wheels. One fish wheel was located along each bank of the river. Previous studies have shown that fish wheels operated at this location can capture large numbers of coho salmon, and captured fish are believed to be representative of all coho salmon migrating past the tag site (Schaberg et al. 2010). In 2008 and 2009, the fish wheels were operated approximately 15 hours a day, 6 days a week from July 18 to September 8. Operational dates were intended to cover the majority of the coho salmon run past the tagging site, while still allowing tagged fish enough time to reach upriver recapture sites prior to the end of their operational period. Coho salmon captured with fish wheels were held for no longer than 1 hour in a live box before being tagged and released.

All captured coho salmon that were deemed healthy were given a primary mark consisting of a brightly colored and uniquely numbered anchor tag. Tags were Floy[1] model FD-68BC. Tag color was specific to each fish wheel. Fish judged to be excessively stressed or injured were not tagged.

A subset of tagged coho salmon was also implanted with radio tags as a means to test mark–recapture assumptions of population closure, capture homogeneity, mixing, and tag retention. Radio tags were model 1840B pulse encoded esophageal transmitters made by Advanced Telemetry Systems. Each radio tag was distinguishable by a unique frequency and encoded pulse pattern. In 2008, 12 frequencies spaced approximately 20 kHz apart in the 148–149 MHz range with 50 encoded pulse patterns per frequency were used, for a total of 600 uniquely identifiable tags. In 2009, 13 frequencies and 50 encoded pulse patterns per frequency were used for a total of 650 uniquely identifiable tags. Fish were selected for tagging following a schedule that attempted to distribute radio tags in proportion to run strength based on historic run timing (Schaberg et al. 2010). Due to the size of the radio transmitters (22 gr), coho salmon of length less than 400 mm were not radiotagged (Winter 1983).

Radiotagged coho salmon were tracked to determine fates as they migrated up the Kuskokwim River using a network of 18 tracking stations and aerial tracking surveys. Tag fates were used to assess mark–recapture assumptions of population closure and tag loss. Stations were positioned at key locations along the mainstem Kuskokwim River and at each of the upriver weirs (Figure 2). Two sets of aerial tracking survey flights were conducted following the end of tagging operations. Each survey set consisted of multiple flights, each focused on a different segment of the drainage. In both years, the majority of the drainage upstream of rkm 233 was flown during the first survey set, and the second survey set was focused on previously non-surveyed areas or areas of special interest. In 2008, the first survey set occurred September 27–October 1, and the

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[1] Product names used in this report are included for scientific completeness but do not constitute product endorsement.

second occurred November 10. In 2009, the first survey set occurred October 3–12, and the second occurred November 6–7.

Only those anchor tagged fish that successfully moved and remained upstream of rkm 294 were considered part of the marked population (M). We anticipated that some number of anchor tagged fish would not move upstream of the tag site; however, the behavior of anchor tagged fish without radio tags could not be observed directly. We assumed that the behavior of radiotagged and anchor tagged coho salmon was the same after tagging. The number of radiotagged fish that moved upstream of the tagging site (n_{rup}), and the total number of radiotagged fish released at tagging site (n_{rm}) was used to estimate the proportion of anchor tagged fish that entered the marked population (p_{up}), where $p_{up}=n_{rup}/n_{rm}$. The expected number of marked fish (M') was estimated as $M \cdot p_{up}$.

Recapture Sampling

Recapture sampling occurred at the 5 tributary weirs upstream of the tagging site. At each location, recapture sampling continued until approximately September 20 each year, and covered most of the coho salmon escapement past each weir. Recapture samples collected at each location (C_i) consisted of all coho salmon that were observed passing upstream of weir i (i=1,…,5) during operable periods. The total number of coho salmon observed at all weir sites ($\sum C_i$) comprised the recapture sample (C). The number of fish passing during inoperable periods was not estimated.

The number of recaptures (R_i) for weir i (i=1,…, 5) consisted of all anchor tagged fish that were observed passing upstream of each weir. The total number of recaptures ($\sum R_i$) was adjusted to account for fish that shed their anchor tag and could not be recognized in the recapture sample events. Adjustments were made using the portion of the marked population that received both an anchor tag and a radio tag. We assumed that staff operating each weir would recognize all double-marked fish that swam through the weir during operable periods, as long as the external anchor tag was still attached. Radiotagged fish that were not visually observed by the weir crew were assumed to have shed the external anchor tag. We used the total number of radiotagged fish detected passing the weir sites using telemetry (n_r) and the total number of those fish visually detected by the weir staff (n_{rt}) to estimate the proportion of all fish that retained the anchor tag (p_{rt}), where $p_{rt}=n_{rt}/n_r$. The expected number of recaptures (R') was estimated as $\sum R_i/p_{rt}$.

Abundance Estimation and Model Assumptions

Chapman's modification of the Petersen estimator (Chapman 1951; Seber 1982) was used to estimate total abundance of coho salmon upstream of rkm 294,

$$\hat{N} = \frac{(M'+1)(C+1)}{R'+1} - 1 . \tag{1}$$

We used data modeling and hypothesis testing to determine whether this study met the critical assumptions of the estimator (Chapman 1951; Seber 1982). The requirement for a closed population was addressed by conducting tagging and recapturing operations throughout most of the coho salmon run and modeling the number of fish that successfully entered the marked population. Limited harvest does occur throughout the mark–recapture study area, but we assumed that tagged and untagged fish were harvested at the same rate. The assumption that tagged fish behave the same as untagged fish could not be formally evaluated, but we attempted to minimize behavioral effects by limiting holding time of captured fish and tagging only healthy fish. The requirement that fish retain their tag and are recognized during the second sample event was addressed by estimating the proportion of fish with tag loss and adjusting the number of recaptures with this proportion. In addition, we tested the assumptions that all fish had an equal probability of capture in the first (marking) and second (recapture) samples and that tagged fish mixed completely with untagged fish. Test procedures followed recommendations outlined in Schaberg et al. 2012.

Variance Estimation

Variance of the mark–recapture estimates was estimated with a parametric bootstrap simulation with 1,000 replicates (Efron 1982). Each uncertain parameter, M', p_{rt}, and R' associated with the tagging and recapturing processes was modeled, denoted in subsequent equations with an asterisk (*). With each bootstrap replicate, denoted with subscript (b), a probable value for each parameter was drawn from an assumed distribution and a bootstrap estimate of simulated abundance was calculated using equation 1.

The number of tagged fish that moved upstream was assumed to have a binomial distribution (BN), and was modeled by, $M^*_{(b)} \sim BN(M, p_{up})$. The proportion of tagged fish out of all tagged fish that entered the marked population, $p_{up,}$ was separated into 6 classes (i = 0,…, 5) as follows:

1) entered marked population but moved to non-terminal area or harvested (p_0);

2) moved upstream of Salmon River weir (p_1);

3) moved upstream of George River weir (p_2);

4) moved upstream of Kogrukluk River weir (p_3);

5) moved upstream of Tatlawiksuk River weir (p_4),;and

6) moved upstream of Takotna River weir (p_5).

Tagged fish were assumed to be distributed among these classes by a multinomial distribution; and the number in each class R_i was modeled by $R^*_{(b),i} \sim multi(M^*_{(b)}, p_i)$. The proportion of tagged fish that retained their anchor tag was modeled as a binomial process, $p^*_{(b)rt} \sim BN(n_r, p_{rt}) / n_r$. The total number of fish recovered was then modeled as, $R^*_{(b)} = (\sum R^*_{(b)i}) / p^*_{(b)rt}$.

The average bootstrap estimate of simulated abundance $\overline{N}^*_{(b)}$ calculated as $(\Sigma N^*_{(b)}) / 1{,}000$ was used to approximate variance of the mark–recapture estimate, using the following equation:

$$v(\hat{N}) = \frac{\sum_{(b)} (N^*_{(b)} - \overline{N}^*_{(b)})^2}{B - 1} \quad . \tag{2}$$

Reanalysis of Coho Salmon Abundance Upstream of Birch Tree Crossing, 2001–2005

Mark–recapture estimates are available for 2001–2005 (Schaberg et al. 2010) based on external tags. Uncertainties associated with tagged fish migrating downstream out of the study area and tag loss were identified but ignored because design limitations precluded those potential biases from being quantified. However, the 2008 and 2009 radiotelemetry studies provided information on downstream movement and tag loss of radiotagged coho salmon under similar capture and handling conditions. Therefore, we used information from the radiotelemetry studies to revise the 2001–2005 estimates and address expected bias.

Given the similarity in capture and handling methods used between all years (2001–2005, 2008 and 2009) we assumed that the average observed proportion of tagged fish that successfully resumed upstream migration after tagging in 2008 and 2009 was similar to that in prior years. Similarly, we assumed that the average proportion of tagged fish that retained their external anchor tag in 2008 and 2009 was representative of tag retention in 2005 when the same external tag type was used (Pawluk et al. 2006b). Tag loss was not modeled for years prior to 2005, because a more robust spaghetti tag was used as the primary tag and retention of that tag type, which is sewn through the musculature of the fish, was assumed to be 100% (Kerkvliet and Hamazaki 2002; Kerkvliet et al. 2003; Kerkvliet et al. 2004; Pawluk et al. 2006a). The corrected data for years 2001–2005 were used to produce new estimates of abundance (Equation 1) and associated variance (Equation 2) for those years.

ESCAPEMENT ESTIMATES DOWNSTREAM OF BIRCH TREE CROSSING

Six additional tributaries downriver from Birch Tree Crossing that support coho salmon spawning were identified from the ADF&G Anadromous Waters Catalogue (Johnson and Daigneault 2008): Kwethluk, Tuluksak, Eek, Kasigluk, Kisaralik, and Fog rivers. Of those, escapements at Kwethluk and Tuluksak rivers are monitored using weirs, and fish counts were assumed to be without error (Miller and Harper 2010a, 2010b; Figure 2). The escapement at the remaining 4 unmonitored tributaries (Eek, Kasigluk, Kisaralik, and Fog rivers), were assumed to be proportional to relative size of the monitored tributaries. For scaling, we used a model (Bradford et al. 1997) that estimates coho salmon smolt abundance ($\hat{S}$) based on stream length ($\hat{L}$),

$$\ln(\hat{S}) = 6.9 + 0.97\ln(\hat{L}) + \varepsilon\,, \tag{3}$$

where

$$\varepsilon \sim N(0,\sigma^2)\,.$$

We assumed that the ratio of annual escapements to monitored (N_{yM}) and unmonitored rivers ($\hat{N}_{yU}$) were proportional to the ratio of average smolt abundance for monitored ($\hat{S}_M$) and unmonitored ($\hat{S}_U$) rivers (Bradford et al. 1997). Escapements of unmonitored rivers was estimated as

$$\hat{N}_{yU} = \frac{\hat{S}_u}{\hat{S}_M} N_{yM}\,. \tag{4}$$

In this expansion, total stream length of all 6 tributaries was calculated using ArcGIS 10.1 (National Hydrology Dataset and Hydrologic Unit Code 12). Based on location and similarities in habitat characteristics, escapement of Eek, Kasigluk, and Kisaralik rivers was estimated using Kwethluk River fish counts, and the Fog River was estimated using Tuluksak River counts.

Total estimated escapement of coho salmon to the lower Kuskokwim River ($\hat{N}_{yL}$) was a sum of estimated escapements in unmonitored ($\hat{N}_{yU}$) tributaries (i = (1) Eek, (2) Kasigluk, (3) Kisaralik, and (4) Fog rivers) and fish counts in monitored (N_{yM}) tributaries (j = (1) Kwethluk, and (2) Tuluksak rivers), as:

$$\hat{N}_{yL} = \sum_i \hat{N}_{yU,i} + \sum_j N_{yM,j} \quad . \tag{5}$$

Variance Estimation of Lower Kuskokwim River Escapement

Variance ($\hat{\sigma}^2$) of Lower Kuskokwim River escapement was estimated as the sum of the variance of monitored and unmonitored escapements. Variances of the 2 monitored escapements (Kwethluk and Tuluksak rivers) were assumed to be zero. Because estimates of smolt abundance (i.e., $\hat{S}_M$, $\hat{S}_U$) were log-normally distributed (Equation 3; Bradford et al. 1997), variance of the 4 unmonitored rivers was estimated analytically using the following equations:

$$\hat{\sigma}^2(\hat{N}_{yU}) = (N_{yM})^2 \hat{\sigma}^2\left(\hat{S}_U / \hat{S}_M\right), \tag{6}$$

and

$$\hat{\sigma}^2(\hat{S}_U / \hat{S}_M) = \hat{\sigma}_U^2 + \hat{\sigma}_M^2 - 2\hat{\rho}_{UM}\hat{\sigma}_U\hat{\sigma}_M \tag{7}$$

where

$\hat{\rho}_{UM}$ is the estimated covariance of coho salmon abundance between unmonitored and monitored tributaries ,

and

$$\hat{S}_U \sim LN(\overline{x}_U, \hat{\sigma}_U^2), \hat{S}_M \sim LN(\overline{x}_M, \hat{\sigma}_M^2) \, .$$

While variance of the regression (Bradford et al. 1997) was not published, we were able to recalculate it from the published raw data, which was 0.7849. We estimated covariance ($\hat{\rho}_{UM}$) as the median estimate of the correlation coefficients among the 6 Kuskokwim River weir escapement counts of coho salmon, from 1991 to 2012 (Appendix A) ($\hat{\rho}_{UM}$ = 0.65). From those, the log-normal variance of $\hat{S}_U / \hat{S}_M$ was calculated to be 0.549.

Upper and lower 95% confidential interval bounds were estimated by taking 2.5% and 97.5% percentile of the 1,000 parametric bootstrap samples (Efron 1982).

HARVEST ESTIMATES DOWNSTREAM OF BIRCH TREE CROSSING

Harvest data downstream of Birch Tree Crossing were available from other sources. Subsistence harvest ($\hat{H}_{sub,y}$), was estimated from survey responses from 18 communities ranging from Tuntutuliak (rkm 45) to Upper Kalskag (rkm 263) including 3 North Kuskokwim Bay communities (Hamazaki 2011; Table 1). Commercial harvest ($H_{c,y}$) was from District W-1, defined as the mainstem Kuskokwim River from the southern tip of Eek Island upriver to Bogus

Creek. Test fish harvest ($H_{test,y}$) was from a test fishery located near Bethel. Commercial and test fish harvest data were from fish tickets (Bavilla et al. 2010) and were assumed to be without error. We used the total Kuskokwim River sport fishery harvest because of the small number of fish and the difficulty in parsing out sport harvest by area (John Chythlook, Sport Fishery Biologist, ADF&G, Fairbanks; personal communication). Sport fish harvest was assumed to be without error.

Total annual harvest of coho salmon downstream of rkm 294 ($\hat{H}_y$) was estimated by summing individual harvest components, where

$$\hat{H}_y = \hat{H}_{sub,y} + H_{c,y} + H_{sp,y} + H_{test,y} \quad . \tag{8}$$

ESTIMATES OF TOTAL ANNUAL RETURN

Total annual return of coho salmon to the Kuskokwim River ($\hat{R}_{y,total}$) was estimated by summing 1) abundance upstream of Birch Tree Crossing ($\hat{N}_y$) from mark–recapture, 2) escapement in tributaries downstream of Birch Tree Crossing ($\hat{N}_{yL}$) from weirs and habitat-based expansions; and, 3) harvest downstream of Birch Tree Crossing ($\hat{H}_y$):

$$\hat{R}_{y,total} = \hat{N}_y + \hat{N}_{yL} + \hat{H}_y \quad . \tag{9}$$

Variance of each of the 3 components $\hat{N}_y$, $\hat{N}_{yL}$, and $\hat{H}_y$ was estimated with a parametric bootstrap simulation with 1,000 replicates (Efron 1982) where all uncertain variables were modeled. Upper and lower 95% confidential interval bounds of total return were estimated by taking the 2.5% and 97.5% percentile of the 1,000 bootstrap replicates.

RESULTS

ABUNDANCE UPSTREAM OF BIRCH TREE CROSSING, 2008 AND 2009

Tag Deployment and Recovery

A total of 3,221 and 821 coho salmon were captured in 2008 and 2009, respectively. In 2008, 3,112 (97%) fish were externally tagged, of which 608 (20%) also received a radio tag. In 2009, 758 (92%) were externally tagged, of which 437 (58%) also received a radio tag. The percentage of radiotagged fish that successfully entered the marked population was 79% in 2008 and 77% in 2009. The number of anchor-tagged coho salmon that migrated upstream and successfully entered the marked population (*M'*) was estimated to be 2,452 in 2008 and 587 in 2009 (Table 2).

Totals of 72,477 coho salmon in 2008 and 52,840 coho salmon in 2009 were observed passing recovery weirs and examined for tags. Totals of 303 tagged coho salmon in 2008 and 57 tagged coho salmon in 2009 were identified. Based on comparisons of radio tagged fish identified through telemetry data and weir observations in 2008 and 2009, we estimated 91% and 86% of tagged fish that entered the marked population retained the external anchor tag until the recapture sample event. The corrected total number of tag recoveries (*R'*) was estimated to be 333 in 2008 and 66 in 2009 (Table 3).

Diagnostics

Conditions for an unbiased estimate of abundance were achieved in 2008. In 2008, the marked fraction of coho salmon at each weir was significantly different (P = 0.03795) indicating that tags were not distributed proportionately among stocks represented at the weirs (Table 4). However, the marked fraction across all weirs did not vary significantly throughout the 2008 season (P = 0.15891) providing support for the assumption of equal probability of recapture (Table 5) (Seber 1982). Test results suggest that tagged fish did not completely mix with untagged fish (P = <0.0001); however, those results were heavily influenced by fish bound for Salmon River weir in the Aniak River drainage (Table 6). The Aniak River joins the Kuskokwim River 37 rkm upstream of the tag site on river left (rkm 307). Fish bound for Salmon River were captured almost exclusively from the left bank fish wheel, and it appears those tagged fish did not mix completely with untagged fish. However, test results indicate that tagged fish bound for tributaries upriver of the Aniak River drainage did mix completely with untagged fish (P = 0.55707). Large sample sizes were available for detecting sex and length biases (Table 7). There was no evidence that sampling during the first or second events were selective for fish size or sex (Table 8 and 9).

Conditions for an unbiased estimate of abundance were achieved in 2009. In 2009, the marked fraction of coho salmon at each weir did not differ significantly (P = 0.12583) indicating that tags were distributed proportionally among stocks represented at the weirs (Table 4). Additionally, there was no evidence that the marked fraction observed across all weirs varied significantly throughout the 2009 season (P = 0.21032) supporting the assumption of equal probability of recapture (Table 5). Complete mixing of tagged and untagged fish could not be tested in 2009 due to low numbers of tag recoveries at Salmon, Tatlawiksuk, and Takotna weirs (Table 3). Sample sizes for detecting sex and length bias in 2009 were large (Table 7). There was no evidence that sampling during the first or second events were selective for fish size or sex (Table 8 and 9).

Abundance Estimates

In 2008, the estimated abundance of coho salmon upstream of Birch Tree Crossing was 532,769 fish (95% (CI) Confidence Interval: 467,307–606,176) (Table 10). In 2009, estimated abundance upstream of Birch Tree Crossing was 464,388 fish (95% CI: 358,318–617,426).

REANALYSIS OF COHO SALMON ABUNDANCE UPSTREAM OF BIRCH TREE CROSSING, 2001–2005

Coho salmon abundance estimates upstream of Birch Tree Crossing for 2001–2005 ranged from a minimum of 344,146 fish (95% CI: 291,581–419,538) in 2001 to a maximum of 1,207,446 fish (95% CI: 1,019,661–1,471,611) in 2004 (Table 10). The differences between the adjusted estimates and previously published estimates (Schaberg et al. 2010) were reductions of 22%–31% primarily due to bias stemming from a number of tagged coho salmon that likely did not successfully enter the study area in those years.

ESCAPEMENT ESTIMATES DOWNSTREAM OF BIRCH TREE CROSSING

Estimates of escapement to the Eek, Kasigluk, and Kisaralik rivers were based on habitat expansion factors of 1.49, 0.65, and 1.40 applied to the annual escapement monitored at the Kwethluk River weir (Table 11). Estimates of escapement to the Fog River were based on a habitat expansion factor of 0.96 applied to the annual escapement monitored at the Tuluksak River weir. Estimates could not be produced for Eek, Kasigluk, or Kisaralik rivers in 2005 because the Kwethluk River weir did not operate. Estimates of coho salmon escapements to the Eek (30,920–162,881 fish), Kasigluk (13,495–71,085 fish), Kisaralik (29,067–153,116 fish), and Fog (7,184–39,568 fish) rivers varied consistent with the observed variation in coho abundance at nearby surrogate (Kwethluk and Tuluksak) systems (Table 11). Total coho salmon escapement to the lower Kuskokwim River for years 2001–2004, 2008, and 2009 ranged between 115,582 fish (95% CI: 75,447–260,396) in 2009 and 576,883 fish (95% CI: 380,508–1,438,493) in 2003 (Table 11).

ESTIMATES OF TOTAL ANNUAL RETURN

Estimates of total run size were reconstructed for all years, except 2005 because for that year lower river escapement could not be determined. Estimates of the total Kuskokwim River coho salmon run ranged from 603,414 fish (95% CI: 546,298–785,349) in 2002 to 2,024,571 fish (95% CI: 1,811,785–2,581,274) in 2004 (Table 12). The proportions of the total reconstructed abundance from mark–recapture, lower river escapement, and harvest were mostly consistent across years (Table 13). Across all years (2001–2004, 2008 and 2009), abundance upstream of Birch Tree Crossing was 46–65%, escapement below Birch Tree Crossing was 16–35%, and harvest rate was 19– 31% of the total run.

DISCUSSION

This report presents the first estimates of total Kuskokwim River coho salmon run size. The time series of estimates from 2001 to 2004, 2008, and 2009 were reconstructed using the most complete and accurate data available. Consideration of study design measures along with diagnostic test results suggest that potential bias was appropriately addressed and accounted for when possible. Based on our familiarity with the Kuskokwim River, we believe that the mark–recapture, lower river escapement, and harvest estimates are appropriate for reconstructing total run size. We feel that the precision of our estimates is realistic given the challenges to estimating total annual return of coho salmon to a large and complex system. A more thorough discussion of the basis for these appraisals of precision and bias follows.

The harvest data used to reconstruct total abundance of coho salmon has a high level of precision. Commercial catch represented the majority (69%–90%) of total harvest each year, and estimates are assumed to be a complete reporting of all commercially harvested coho salmon (Brazil et al. 2013). Subsistence catch was the second largest component of total harvest, representing 9%–27% annually. Subsistence estimates are from household surveys conducted throughout each community within the Kuskokwim River drainage. Survey coverage was good each year with a high of 62% of households participating in 2002 and a low of 23% participation in 2008 (mean 48.5%; Hamazaki 2011). Precision of subsistence estimates is high (CV 3%–14%; Table 1). The contribution of subsistence data uncertainty to total uncertainty of reconstructed estimates was negligible (mean < 1%) across all years. Test fish and sport harvests combined for less than 5% of the total harvest each year. Test fish harvest was assumed to be a complete record of annual harvest (Bue and Brazil 2012). Considerable uncertainty exists with estimates of sport harvest from angler surveys but, given the small contribution to the total reconstructed abundance, that uncertainty was ignored.

The mark–recapture estimates of abundance upriver of Birch Tree Crossing were the single largest component (mean 56%) of the reconstructed estimates of total abundance. Results indicate that estimates are approximately unbiased and precision was high (CV 4%–15%; Table 10). The contribution of mark–recapture data uncertainty to the total uncertainty of reconstructed estimates averaged 24% among all years.

Several study design considerations were important for unbiased and precise mark–recapture abundance estimates. First, operation of capture gears along both banks of the river was crucial to ensure that all upriver spawning stocks had a non-zero probability of capture – this was particularly important to ensure adequate capture of fish bound for the Aniak River. Second, the number and distribution of weir recapture sites was important to ensure adequate recapture sampling and large sample sizes for testing assumptions related to capture homogeneity and mixing. In particular, the addition of the Salmon River weir in 2008 and 2009 allowed for tag recovery and diagnostic testing for the Aniak River, which is a very large component of the middle river escapement. Finally, the incorporation of radio telemetry techniques provided an opportunity to evaluate 2 critical assumptions, tag retention and population closure, which were identified in previous studies (2001–2005) but not fully addressed.

We found that a substantial percentage of tagged fish (9–14%) did lose their anchor tag and were therefore not susceptible to capture during the 2008 and 2009 recapture events. We determined it was necessary to adjust the 2005 mark-recapture estimated to account for tag loss in order to produce an unbiased estimate. This finding was in contrast to initial 2005 results, which found no evidence of tag loss (Pawluk et al. 2006b). In 2005, each coho salmon tagged near Kalskag was given a secondary mark, which consisted of removing the adipose fin. Tag loss was investigated during routine sampling for age, sex, and length at each weir site, and on average 10% of the annual escapement at each project was evaluated for evidence of tag loss (range: 2%–25%; Brodersen et al. 2013). In 2005, tagged fish made up <1% of the coho salmon past all weir sites. As a result, the probability that any tagged fish would be captured during routing sample was very small, and it is reasonable to assume that the lack of evidence for tag loss was due to low power to detect tag loss. In 2008 and 2009, use of a radio tag as a secondary mark and tracking tagged fish past each weir resulted in relatively large numbers of tagged fish evaluated for anchor tag loss (56 in 2008 and 37 in 2009), and provided relevant information for revising the 2005 estimate.

In all project years (2001–2005, 2008, and 2009) anchor tagged fish were recaptured downriver, demonstrating a clear violation of the assumption of population closure. Given information from the 2008 and 2009 radio telemetry component, it was clear that our capture and handling methods resulted in a meaningful and relatively consistent proportion of tagged fish that did not remain in the marked population. Failure to exclude these fish from the marked population would result in over estimating abundance. Given the similarity of capture and handling methods used across all years (2001–2005, 2008, and 2009) we expect that the original 2001–2005 estimates were likely biased and a revisions were warranted. Revised estimates made in this study were based on the assumption that the behavior of radiotagged coho salmon was representative of fish marked with external tags only, but that assumption could not be tested. It is probable that radiotagged fish migrated downriver at a higher rate than anchor tagged fish due to the more invasive tagging methods. However, the radiotelemetry data was the best information available.

We consider our methodology for estimating coho salmon escapement into the unmonitored tributaries of the lower Kuskokwim River to be the weakest component of the reconstructed total run estimates. Across all years, estimates for unmonitored tributaries averaged 22% of the total reconstructed abundance but represented 75% of the total variance. Uncertainties are from 2 primary sources: 1) our approach to index differences in productivity between monitored and unmonitored tributaries and 2) appropriateness of using Kwethluk River weir data to represent unmonitored tributaries.

The average number of coho salmon smolt is an appropriate measure of a streams potential to produce coho salmon (Bradford et al. 1997). By extension, the ratio of mean smolt abundance for any 2 systems is a reasonable estimate of the relative production between those 2 tributaries. The unestimated uncertainty in this approach originates with estimating coho smolt abundance with a habitat model and then assuming a constant relationship between smolt abundance and adult returns. The model we used was developed using data from 83 streams including 3 from southeast Alaska. Unfortunately, the model did not incorporate any data from the Kuskokwim River or western Alaska (Bradford et al. 1997), and the streams used to develop the model were generally smaller than the unmonitored tributaries in the lower Kuskokwim River. Bradford et al. (1997) acknowledge that the precision of their model is suitable for general uses, but reliable estimates for individual streams would require more site-specific information and data intensive habitat models. We are reasonably confident that the total lower river escapement estimate is appropriate for reconstructing total run size, but we caution the use of individual estimates for Eek, Kasigluk, and Kisaralik.

The Riverscape Analysis Project (RAP) (http://rap.ntsg.umt.edu/) indicates that the Kwethluk River is complex and highly conducive to salmon spawning and rearing. Our methods, to scale Kwethluk River weir counts to unmonitored tributaries relied solely on stream length. Failure to account for differences in available rearing habitat could influence our estimates of relative productivity between systems. We considered using data from RAP to produce estimates of usable habitat, similar to what was done for Chinook salmon in the lower Kuskokwim River (Schaberg et al. 2012). However, those methods excluded the important floodplain habitats in lower reaches of each tributary. We also considered excluding all portions of the drainage with an average gradient > 3% (Bradford et al. 1997). However, that approach excluded headwater areas known to support coho salmon based on extensive aerial survey tracking of radiotagged fish (data on file with the Kuskokwim Research Group, contact Kevin Schaberg, ADF&G Division of Commercial Fisheries; Anchorage). Calculating total stream length is easily reproduced and conformed to our understanding of coho salmon distribution from radiotelemetry survey flights.

Estimating the entire coho salmon run was not realistic because coho salmon continue their migration late into the fall. However, our estimates are suitable to represent the abundance of coho salmon vulnerable to harvest in commercial and subsistence fisheries which typically end by late August. The percentage of the run entering the mark–recapture study area after tagging efforts ceased is assumed to be negligible based on run timing data from a lower river test fishery and coho salmon migration patterns. Test fish harvest of coho salmon near Bethel (164 km downriver from the tag site) generally ends around August 23 and covers the majority of the coho salmon migration (Bue and Brazil 2012). Coho salmon travel speed near Kalskag has been estimated to be approximately14 rkm/day (Schaberg et al. 2010). Based on that speed it would take fish approximately 12 days to travel between Bethel and the tag site, which suggests that most coho salmon would have passed the tagging site before tagging ended on September 8. Furthermore, results from other tagging studies indicate that run timing past Kalskag is similar among upriver stocks (Schaberg et al. 2010). Therefore, even if the end of the coho salmon run was not represented in the marked population, our estimates would be approximately unbiased as long as tag recapture efforts continued throughout the entire season. Recapture operations generally ceased by September 20 because it is thought most of the coho salmon escapement has been counted by that time. In years when weirs have operated beyond September 20, counts of coho salmon have accounted for 0.1%–2.1% of the total escapement (Ward et al. 2003).

Although estimated variability is substantial, our estimates of total abundance of Kuskokwim River coho salmon provide useful fisheries management information. For example, in 2008, the ADF&G Division of Commercial Fisheries began development of a maximum likelihood (MLE) model to reconstruct total annual returns of Kuskokwim River coho salmon back to 1981. The approach was based on methods presented by Shotwell and Adkison (2004) and subsequent modifications by Bue et al. (2008 and 2012) for estimating salmon abundance in data limited situations. The success of this modeling initiative is reliant on independent estimates of total abundance for scaling purposes. Our estimates of abundance of coho salmon for 2001–2004, 2008, and 2009 are appropriate for scaling an MLE model given that the uncertainty in our estimates is incorporated in the model development. If successful, completion of the MLE model and a brood table would greatly inform sustainable management of Kuskokwim River coho salmon through additional analyses such as investigating drainage-wide production.

Our estimates are appropriate for a range of future analyses such as historical run reconstructions and spawner-recruit analyses. For example, ADF&G recently completed a run reconstruction and spawner-recruit analysis for Kuskokwim Chinook salmon (Bue et al. 2012; Hamazaki et al. 2012). Those analyses incorporated independent estimates of total abundance reconstructed using similar methods described in this report for coho salmon (Schaberg et al. 2012).

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TABLES AND FIGURES

Table 1.–Estimates of subsistence harvest by community for the Kuskokwim River downstream of Birch Tree Crossing, 2001–2005, 2008 and 2009.

Community	2001	2002	2003	2004	2005	2008	2009
Kipnuk	–	–	–	3,448	–	–	–
Kwigillingok	–	–	–	–	–	–	–
Kongiganak	919	1,138	236	937	740	551	588
Tuntutuliak	335	1,239	2,092	1,189	1,074	1,348	359
Eek	241	821	747	1,018	378	724	176
Kasigluk	1,191	2,902	2,052	5,034	1,396	917	628
Nunapitchuk	425	821	627	555	807	495	286
Atmautluak	375	612	283	744	530	266	68
Napakiak	667	793	992	1,648	742	1,375	428
Napaskiak	455	717	983	655	602	816	755
Oscarville	90	161	19	304	60	62	67
Bethel	14,108	15,489	15,062	17,040	12,994	16,998	13,037
Kwethluk	1,773	2,706	1,787	3,430	3,048	6,867	4,044
Akiachak	1,912	1,690	1,627	2,397	1,817	4,132	1,593
Akiak	594	1,136	1,094	1,342	1,847	1,260	661
Tuluksak	1,136	1,349	921	1,007	484	777	857
Lower Kalskag	597	281	314	368	319	95	318
Upper Kalskag	536	1,069	462	1,500	594	2,063	181
Kuskokwim River Below Birch Tree Crossing	25,354	32,924	29,298	42,616	27,432	38,746	24,046
Lower 95% CI	23,520	31,053	26,549	34,629	25,924	28,476	19,762
Upper 95% CI	27,187	34,796	32,046	50,603	28,941	49,015	28,330
CV%	4%	3%	5%	10%	3%	14%	9%

Source: Hamazaki 2011.

Table 2.–Number of coho salmon tagged at the Kalskag fish wheels and considered part of the marked (M') population for abundance estimation, 2001–2005, 2008 and 2009.

		Tagged			Radio Tag Fate			
Year [a]	Total Catch	Anchor Tag [b]	Radio Tag [c]	Total (M)	Entered Marked Population [d]	Dropped Out [e]	Success Rate (P_{up}) [f]	Number of Tags Available for Recapture (M') [g]
2001	1,363	1,290	–	1,290	–	–	78%	1,008
2002	3,005	2,804	–	2,804	–	–	78%	2,189
2003	7,148	6,766	–	6,766	–	–	78%	5,282
2004	3,035	2,964	–	2,964	–	–	78%	2,314
2005	5,708	5,497	–	5,497	–	–	78%	4,292
2008	3,221	2,504	608	3,112	479	129	79%	2,452
2009	821	321	437	758	338	99	77%	587

[a] Catch and tag data for 2001 to 2005 are from Schaberg et al. 2010.
[b] Spaghetti tags were used from 2001 to 2004. T-bar anchor tags were used from 2005 to 2009.
[c] Radio tags were deployed in 2008 and 2009 to evaluate tagging success.
[d] Fish that successfully entered and remained within the study area upstream of Birch Tree Crossing.
[e] Fish that did not enter or remain within the study area upstream of Birch Tree Crossing.
[f] Years 2001 to 2005 expected success rate was the average of 2008 and 2009.
[g] Estimated using the annual success rate of radiotagged fish.

Table 3.–Number of coho salmon observed at each upriver recapture site and considered part of capture (C) and recapture (R') populations for abundance estimation, 2001–2005, 2008 and 2009.

			Tag Recaptures [a]			Tag Loss			
Year	Recapture Location	Weir Passage (C)	Anchor Tag	Radio Tag [b]	Total (R)	Inspected [c]	Counted [d]	Tag Retention (P_{rt}) [e]	Corrected Recaptures (R') [f]
2001	George River	8,802	26	–	26	–	–		
	Tatlawiksuk River	5,669	7	–	7	–	–		
	Kogrukluk River	18,308	66	–	66	–	–		
	Takotna River	2,351	3	–	3	–	–		
	Total	35,130	102	–	102	–	–	100%	102
2002	George River	6,759	41	–	41	–	–		
	Tatlawiksuk River	11,132	56	–	56	–	–		
	Kogrukluk River	14,501	108	–	108	–	–		
	Takotna River	3,982	19	–	19	–	–		
	Total	36,374	224	–	224	–	–	100%	224
2003	George River	31,925	220	–	220	–	–		
	Tatlawiksuk River [g]	–	–	–	0	–	–		
	Kogrukluk River	68,718	492	–	492	–	–		
	Takotna River	7,122	38	–	38	–	–		
	Total	107,765	750	–	750	–	–	100%	750
2004	George River	13,248	21	–	21	–	–		
	Tatlawiksuk River	16,410	35	–	35	–	–		
	Kogrukluk River	26,078	51	–	51	–	–		
	Takotna River	3,201	5	–	5	–	–		
	Total	58,937	112	–	112	–	–	100%	112
2005	George River	8,197	82	–	82	–	–		
	Tatlawiksuk River	6,746	31	–	31	–	–		
	Kogrukluk River	23,102	203	–	203	–	–		
	Takotna River	2,209	15	–	15	–	–		
	Total	40,254	331	–	331	–	–	89%	373
2008	Salmon River	11,022	34	2	36	2	2		
	George River	21,956	97	14	111	16	14		
	Tatlawiksuk River	11,018	42	12	54	12	11		
	Kogrukluk River	25,650	67	24	91	25	23		
	Takotna River	2,831	10	1	11	1	1		
	Total	72,477	250	53	303	56	51	91%	333

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Table 3.–Page 2 of 2.

Year	Recapture Location	Weir Passage (C)	Tag Recaptures [a] Anchor Tag	Radio Tag [b]	Total (R)	Tag Loss Inspected [c]	Counted [d]	Tag Retention (P_{rt}) [e]	Corrected Recaptures (R′) [f]
2009	Salmon River	6,391	2	2	4	3	2		
	George River	12,316	8	6	14	6	5		
	Tatlawiksuk River	10,155	2	3	5	4	3		
	Kogrukluk River	21,337	7	21	28	23	21		
	Takotna River	2,641	5	1	6	1	1		
	Total	52,840	24	33	57	37	32	86%	66

[a] Recapture data for years 2001–2005 from Schaberg et al. 2010.

[b] Radio tags were deployed in 2008 and 2009 to evaluate retention of external anchor tags.

[c] Number of radio tagged fish that passed upstream of a weir that was detected by tracking station located at the weir site. Radio tagged fish also had an external anchor tag.

[d] Number of radiotagged fish detected by tracking station that were recorded by weir crews after visual observation of external anchor tag.

[e] Estimated from radio tag and weir recovery data. Assumed to 100% for years 2001–2004, when spaghetti tags were used and were unlikely to be shed. Year 2005 was estimated as the average from 2008 and 2009.

[f] Corrected based on estimates of tag loss.

[g] Tatlawiksuk weir did not operate in 2003 due to high water and extensive weir damage.

Table 4.–Tag recovery ratios of coho salmon by recovery site, 2008 and 2009.

							Chi Square		
Year	Recapture Location	Distance (rkm) [a]	Sample Size [b]	Total Recaptures [c]	Total Untagged	Ratio [d]	X^2	df	*P-val* [e]
2008	Salmon River	134	11,022	36	10,986	0.0033	2.21386		
	George River	183	21,956	111	21,845	0.0051	4.03716		
	Tatlawiksuk River	298	11,018	54	10,964	0.0049	1.37363		
	Kogrukluk River	440	25,650	91	25,559	0.0036	2.46777		
	Takotna River	565	2,831	11	2,820	0.0039	0.05921		
		Total	72,477	303	72,174	0.0042	10.15163	4	0.03795
2009	Salmon River	134	6,391	4	6,387	0.0006	0.95815		
	George River	183	12,316	14	12,302	0.0011	0.17701		
	Tatlawiksuk River	298	10,155	5	10,150	0.0005	2.74300		
	Kogrukluk River	440	21,337	28	21,309	0.0013	1.84593		
	Takotna River	565	2,727	6	2,721	0.0022	-		
		Total	52,926	57	52,869	0.0011	5.72410	3	0.12583

Note: Includes only tag recaptures reported by weir crews. Analysis does not include radiotagged coho salmon that were known to have passed upstream based on fixed receiver or aerial survey data, but not reported by weir crews.

[a] Distance from Kalskag tagging site.

[b] Equivalent to total observed escapement at weirs. Number of tagged fish plus untagged fish.

[c] Total number of tags reported by weir crews. Recovered plus observed tags.

[d] Total number of tag recaptures divided by total number of untagged fish in sample.

[e] P-value criteria is based on an alpha of 0.05.

Table 5.–Tag recovery ratios of coho salmon by weekly temporal strata, 2008 and 2009.

Year	Temporal Strata [a]	Not Recovered	Recovered	Ratio	Chi Square X^2	df	*P-val* [b]
2008	7/18–7/22	51	5	0.0893	0.01178		
	7/24–7/29	163	21	0.1141	0.92308		
	7/31–8/5	335	47	0.1230	3.92920		
	8/7–8/12	460	48	0.0945	0.00575		
	8/14–8/19	455	38	0.0771	1.57000		
	8/21–8/26	471	57	0.1080	1.29983		
	8/28–9/2	477	42	0.0809	0.96961		
	9/4–9/8	409	33	0.0747	1.85248		
	Total	2,821	291	0.0935	10.56172	7	0.15891
2009	7/18–8/4 [c]	187	13	0.0650	0.03084		
	8/6–8/18 [d]	130	10	0.0714	0.21375		
	8/20–8/25	226	19	0.0776	1.01803		
	8/27–9/8 [e]	168	6	0.0345	3.25961		
	Total	711	48	0.0632	4.52223	3	0.21032

[a] Based on operational week- generally 6 days, Thursday to Tuesday.

[b] P-value criteria is based on an alpha of 0.05.

[c] First 3 weeks were pooled due to low expected tag recoveries.

[d] Weeks 4 and 5 were pooled due to low expected tag recoveries.

[e] Weeks 7 and 8 were pooled due to low expected tag recoveries.

Table 6.–Test of complete mixing of tagged coho salmon in the Kuskokwim River, 2008.

Year	Recovery Location	Distance (rkm) [a]	Recaptures by Tag Location: Right Bank	Recaptures by Tag Location: Left Bank	Chi Square X^2	df	*P-val* [b]
2008	Salmon River	134	3	33	29.391		
	George River	183	63	48	0.5008		
	Tatlawiksuk River	298	23	31	2.5375		
	Kogrukluk River	440	52	39	0.5106		
	Takotna River	565	7	4	0.4626		
	Not Recovered	–	1,525	1,297	0.2733		
	Total		1,673	1,452	33.676	5	<0.0001

[a] Distance from Kalskag tagging site.

[b] P-value criteria is based on an alpha of 0.05.

Table 7.–Number of sex and length samples to be included in the bootstrap sample from each recapture location when testing for selective sampling bias.

Year	Recapture Location	Weir Passage	Available Samples	Percent Sampled	Sample Size
2008	Salmon River	11,022	643	6%	257
	George River	21,956	600	3%	511
	Tatlawiksuk River	11,018	604	5%	256
	Kogrukluk River	25,650	597	2%	597
	Takotna River	2,831	567	20%	66
	Total	72,477	3,011	4%	1,687
2009	Salmon River	6,391	802	13%	180
	George River	12,316	608	5%	347
	Tatlawiksuk River	10,155	615	6%	286
	Kogrukluk River	21,337	601	3%	601
	Takotna River	2,727	445	16%	77
	Total	52,926	3,071	6%	1,491

Note: The number of observations to be included in the bootstrap sample from each weir recapture location was determined using a methodology which maximized the number of samples used in the analysis while ensuring that the ratio of samples to weir passage was the same for each weir.

Table 8.–Results of tests for selective sampling by size in the marked (*M*), captured (*C*), and recaptured (*R*) sample populations of coho salmon using the Kolmogorov-Smirnov test (*D*).

								Test for Selective Sampling					
										Expected [d]		Expected [d]	
	Sample Sizes [a]			Length (mm, MEF)				*M* vs. *R*		*C* vs. *R*		*M* vs. *C*	
Year	*M*	*C*	*R*		*M*	*C* [b]	*R*	*D*	*P-val* [c]	*D*	*P-val*	*D*	*P-val*
2008				Min	357	327	425						
				Max	647	674	612						
	3,105	3,011	291	Mean	540	540	544	0.067	0.175	0.083	0.065	0.032	0.226
2009				Min	405	363	448						
				Max	690	695	660						
	755	3,071	48	Mean	548	547	558	0.138	0.327	0.143	0.299	0.065	0.029

[a] Includes only fish with a length measurement. Number of marked and recaptured fish differ from those used for abundance estimation because not all fish were measured.

[b] Min and max were obtained by pooling all samples from all recapture sites, while mean is the weighted average where the weights are the number of fish counted through the appropriate weir.

[c] H_o: No difference in length distribution between sample populations; $\alpha = 0.05$.

[d] A subset of available samples for (*C*) were selected proportional to abundance for each sample location. Expected *D* is the mean of 10,000 bootstrap samples. P-value is calculated using the expected *D*.

Table 9.–Results of tests for selective sampling by sex in the marked (*M*), captured (*C*), and recaptured (*R*) sample populations of coho salmon, 2008 and 2009, using contingency table analysis (χ^2).

								Test for Selective Sampling					
										Expected [c]		Expected [c]	
	Sample Sizes [a]			Percent Sex Composition				*M* vs. *R*		*C* vs. *R*		*M* vs. *C*	
Year	*M*	*C*	*R*		*M*	*C* [a]	*R*	χ^2	*P-val* [b]	χ^2	*P-val*	χ^2	*P-val*
2008				Male	48.5	47.9	51.9						
	3105	3011	291	Female	51.5	52.1	48.1	1.199	0.274	1.431	0.232	0.348	0.555
2009				Male	55.5	49.1	45.8						
	755	3071	48	Female	44.5	50.9	54.2	1.702	0.192	0.094	0.759	7.799	0.005

[a] Includes only fish with a valid sex determination. Number of marked and recaptured fish differ from those used for abundance estimation because not all fish were successfully sexed.

[b] Percent by sex was estimated by weighting the sex composition from each weir by the number of fish counted through the appropriate weir.

[c] H_o: No difference in the frequency of males and females between sample populations; $\alpha = 0.05$.

[d] A subset of available samples for (*C*) were selected proportional to abundance for each sample location. Expected χ^2 is the mean of 10,000 bootstrap samples. P-value is calculated using the expected χ^2.

Table 10.–Estimates of abundance for coho salmon upstream of Birch Tree Crossing, 2001-2005, 2008 and 2009.

	Project Year						
	2001	2002	2003	2004	2005	2008	2009
Estimate from Schaberg et al. 2010	440,330	453,499	971,266	1,546,627	666,747	-	-
Corrected Abundance Estimate [a]	344,146	354,049	758,092	1,207,446	462,273	532,769	464,388
Lower 95% CI	291,581	314,146	709,844	1,019,661	406,436	467,307	358,318
Upper 95% CI	419,538	403,495	810,313	1,471,611	528,691	606,176	617,426
CV%	12%	8%	4%	12%	6%	7%	15%

[a] The mark (*M*) and recapture (*R*) populations in years 2001-2005 were adjusted to account for the expected number of fish that did not enter the marked population and fish that lost their primary tag. Adjustments were based on 2008 and 2009 radio tagging results.

Table 11.–Estimates of lower Kuskokwim River escapement for monitored and unmonitored tributaries supporting coho salmon, 2001–2005, 2008, and 2009.

					Annual Escapement						
Location	Surrogate	Stream Length (km)	Est. Smolt Abund[a]	Expansion Factor[b]	2001	2002	2003	2004	2005[c]	2008	2009
Monitored Tributary [d]											
Kwethluk River (above weir)		2,587	2,028,195		20,723	23,298	109,163	64,216		49,971	21,911
Tuluksak River (above weir)		1,392	1,111,407		23,768	11,487	41,071	20,336	11,324	7,457	8,137
Unmonitored Tributary [e]											
Eek River	Kwethluk River	3,909	3,026,242	1.49	30,920	34,763	162,881	95,816		74,561	32,693
Kasigluk River	Kwethluk River	1,663	1,320,731	0.65	13,495	15,171	71,085	41,817		32,540	14,268
Kisaralik River	Kwethluk River	3,667	2,844,818	1.40	29,067	32,679	153,116	90,072		70,091	30,733
Fog River	Tuluksak River	1,339	1,070,726	0.96	22,898	11,067	39,568	19,592	10,910	7,184	7,839
Lower Kuskokwim River Escapement					140,871	128,464	576,883	331,848		241,805	115,582
Lower 95% CI					97,234	81,728	380,508	214,615		148,616	75,447
Upper 95% CI					335,139	304,573	1,438,493	820,634		612,116	260,396
CV%					57%	64%	62%	67%		64%	61%

[a] Based on Bradford et al. (1997); ln mean smolt abundance = 6.90+0.97(ln stream length).

[b] Ratio of estimated smolt abundance for monitored and unmonitored system.

[c] Kwethluk River weir did not operate in 2005.

[d] Tributary monitored with a weir.

[e] Tributary known to support coho salmon, but escapement counts not known. Escapement estimated by expanding known escapement from a suitable surrogate systems proportional to watershed area.

Table 12.–Total inriver abundance of coho salmon in the Kuskokwim River, 2001–2005, 2008 and 2009 combining harvest and estimates derived from mark-recapture and watershed area expansion techniques.

	Year						
Component	2001	2002	2003	2004	2005	2008	2009
Abundance Upstream of Birch Tree Crossing	344,146	354,049	758,092	1,207,446	462,273	532,769	464,388
Escapement Downstream of Birch Tree Crossing	140,871	128,464	576,883	331,848	–	241,805	115,582
Lower Kuskokwim River Harvest							
Subsistence [a]	25,354	32,924	29,298	42,616	27,432	38,746	24,046
Commercial [b]	192,998	83,463	284,064	435,407	142,319	142,862	104,546
Bethel Test Fish [c]	1,723	2,484	2,377	2,259	1,499	2,984	2,394
Sport [d]	1,204	2,030	3,459	4,996	3,539	3,893	3,526
Total Harvest	221,279	120,901	319,198	485,278	174,789	188,485	134,512
Total Inriver Abundance	706,296	603,414	1,654,173	2,024,571	–	963,058	714,481
Lower 95% CI	642,493	546,298	1,449,026	1,811,785	–	848,856	605,985
Upper 95% CI	896,892	785,349	2,500,529	2,581,274	–	1,299,578	927,998
CV%	9%	10%	17%	10%	–	13%	12%

[a] Subsistence harvest includes all villages from Kalskag downstream to the mouth of the Kuskokwim River, plus north Kuskokwim Bay village of Kongiganak. Data from Hamazaki 2011.

[b] Commercial and Bethel test fish harvest data from Bavilla et al. (2010).

[c] Bethel test fish harvest from annual test fish files maintained by ADF&G. Harvest numbers for years 2003, 2008, or 2009 were not correctly reported in Bavilla et al. (2010). Corrected harvest is shown here.

[d] Sport harvest from John Chythlook, Sport Fish Biologist (Kuskokwim Area); personal communication.

Table 13.–Composition of Kuskokwim River coho salmon total run, as percent of total run for each major component.

	Year						
Component	2001	2002	2003	2004	2005	2008	2009
Abundance Upstream of Birch Tree Crossing	49%	59%	46%	60%	–	55%	65%
Escapement Downstream of Birch Tree Crossing	20%	21%	35%	16%	–	25%	16%
Total Harvest	31%	20%	19%	24%	–	20%	19%

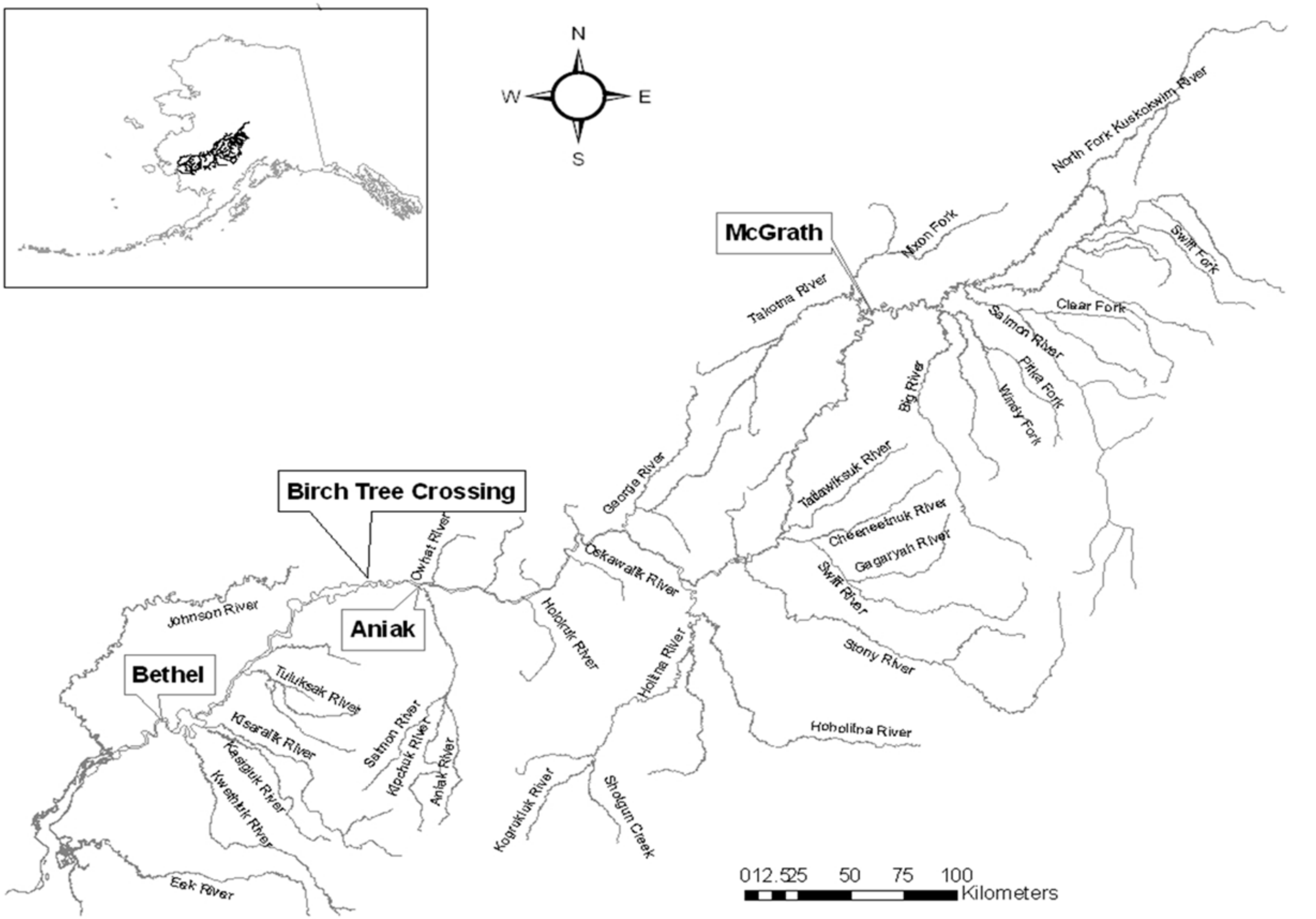

Figure 1.–Kuskokwim River showing major communities, tributary locations, and important reference locations.

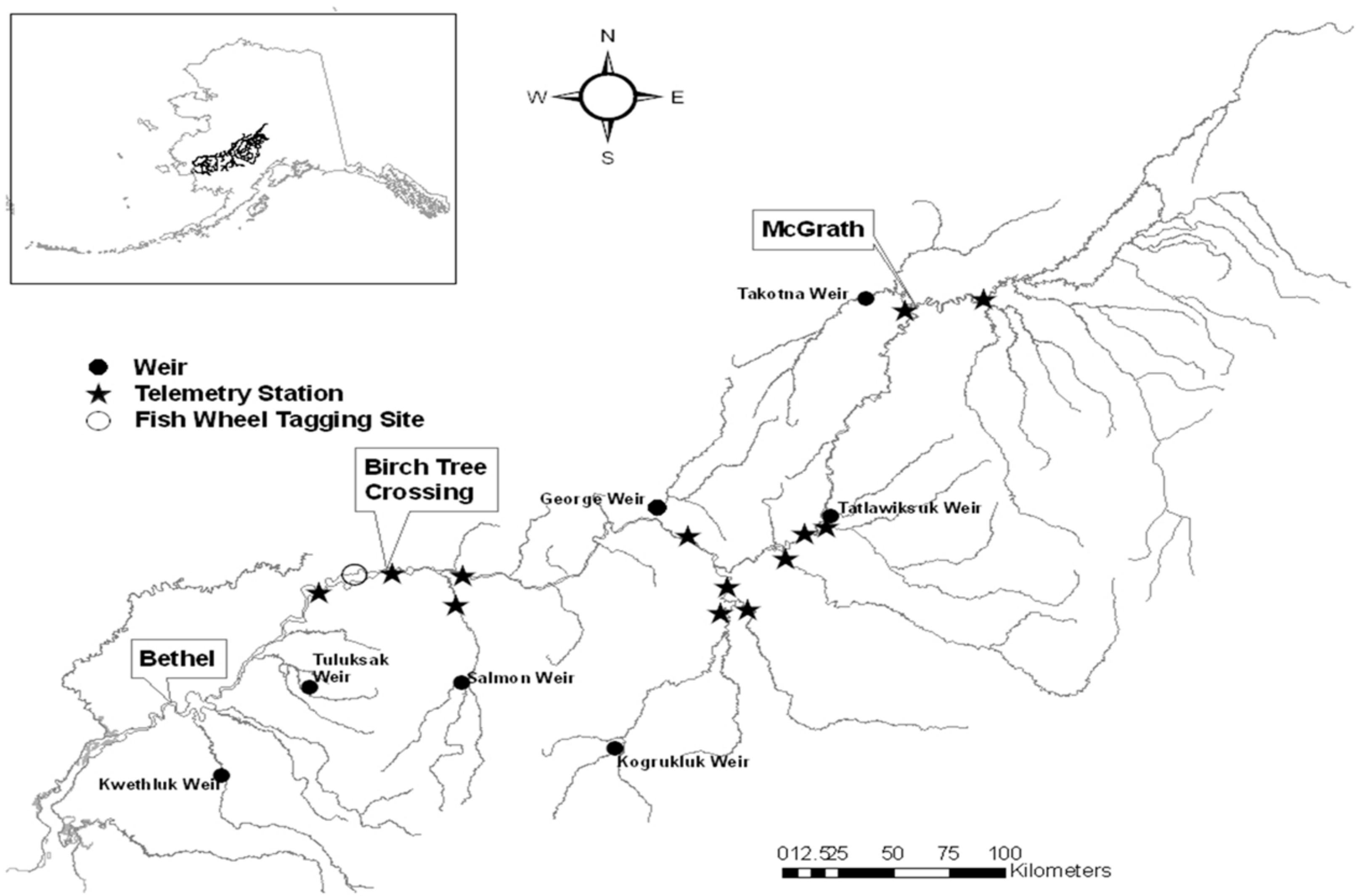

Figure 2.–Kuskokwim River showing location of fish capture event, weirs used for the recapture event, and ground-based telemetry stations.

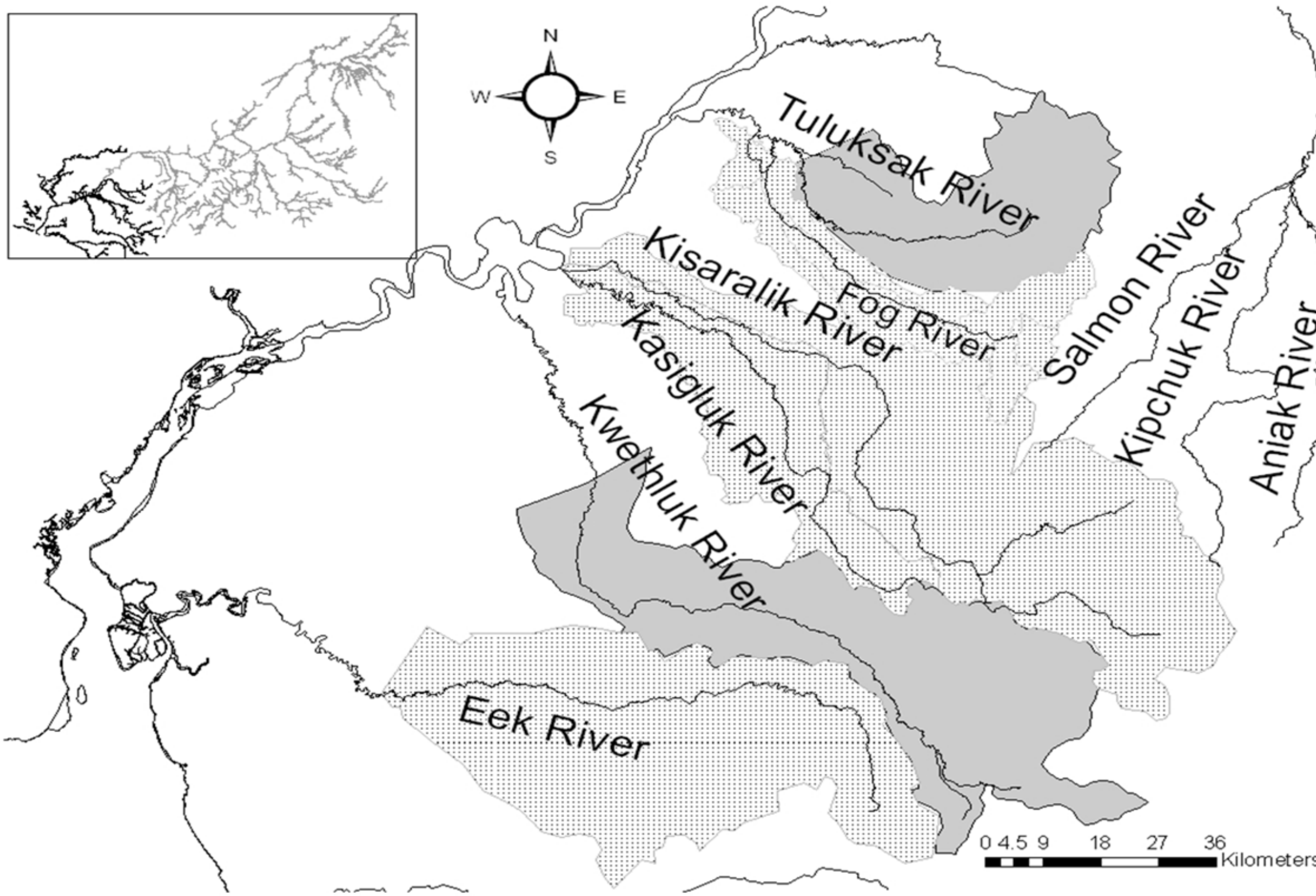

Figure 3.–The lower Kuskokwim River highlighting portions of drainages where coho salmon escapement was monitored (dark shaded) and those portions were escapement was estimated (stippled).

APPENDIX A: ESTIMATION OF COVARIANCE FOR ADULT SALMON ESCAPEMENT INTO UNMONITORED TRIBUTARIES

Appendix A1.–Correlation coefficients among Kuskokwim River coho salmon escapement counts, years 1991–2012, used to inform covariance of coho salmon escapement into unmonitored lower Kuskokwim River tributaries.

	Weir Site					
Weir Site	Kwethluk	Tuluksak	George	Kogrukluk	Tatlawiksuk	Takotna
Kwethluk	1					
Tuluksak	0.782729	1				
George	0.600105	0.402835	1			
Kogrukluk	0.883505	0.775299	0.664729	1		
Tatlawiksuk	0.754746	0.681570	0.298890	0.349351878	1	
Takotna	0.651917	0.585691	0.376616	0.670194182	0.105568113	1

Note: Median correlation coefficient = 0.65.